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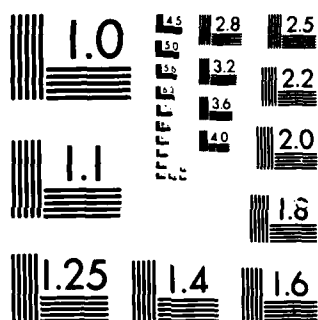
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20. Abstract (cont. from reverse side)

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Professor Charles H. Townes
Professor Reinhard Genzel

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Final Report

FAR INFRARED HETERODYNE DETECTION
WITH GALLIUM DOPED GERMANIUM PHOTOCONDUCTORS

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November 26, 1985

I. Introduction

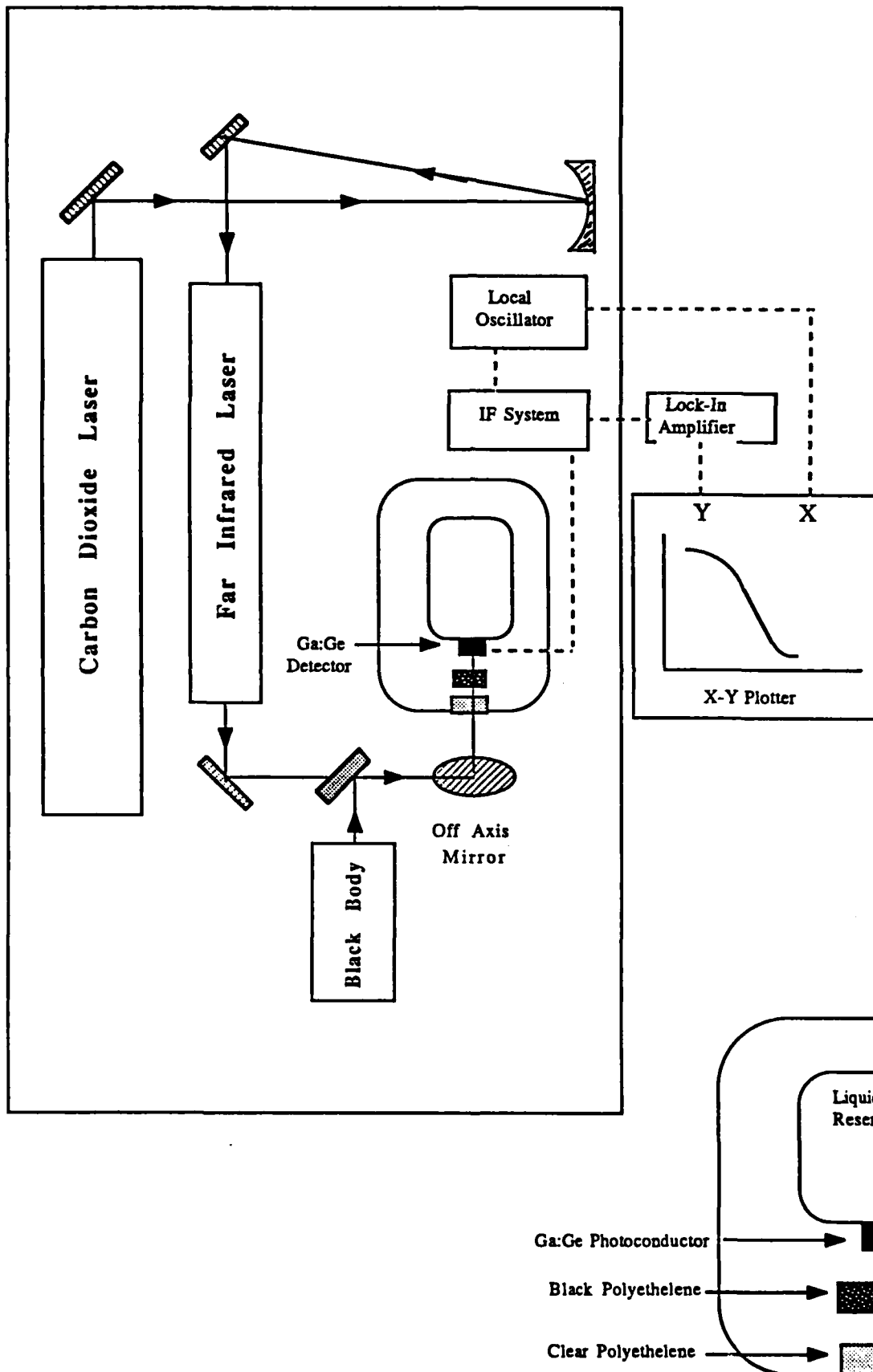
This contract has been directed at examination of the bandwidth and sensitivity of semiconducting heterodyne detectors for far infrared radiation. Germanium detectors variously doped with gallium have been of prime interest. However, HgCdTe detectors have also been tested. The efforts to find good FIR heterodyne detectors have been slow, partly because of the newness of the field. Towards the end of the contract period, however, substantial success was achieved and measurements have continued even past the contract period to round out what we regard as important quantitative measurements of improved detection. We have during these last stages measured faster, more responsive detectors and have reduced our system temperature. In addition, we have seen, for the first time, a change in detector bandwidth with bias voltage. We believe we have proceeded in the correct direction in detector fabrication and doping levels to produce faster detectors while retaining high responsivity.

II. Experimental Setup

Our experimental setup is shown in figure 1. A 20 Watt, single axial mode, frequency stabilized, carbon dioxide laser is used to pump a far infrared (FIR) methanol laser. The FIR laser is operated at $119\text{ }\mu\text{m}$ and produces about 1 m Watt of power. This laser source is used to provide the local oscillator for the RF mixing that takes place in the gallium doped germanium (Ga:Ge) photoconductor. The $119\text{ }\mu\text{m}$ radiation from the FIR laser is combined with the output from a 1300 K blackbody by passing the laser beam through a metal mesh mirror that the blackbody radiation is reflected from. The two radiation beams are then focused, through two optical filters (designed to keep background light from falling on the detector), with an off axis parabolic mirror onto the Ga:Ge photoconductor. The detector is operated in a constant bias voltage mode and is kept at liquid helium temperature. The intermediate frequency (IF)

Figure 1

EXPERIMENTAL SETUP FOR FAR INFRARED HETERODYNE DETECTION WITH GALLIUM DOPED GERMANIUM PHOTOCONDUCTORS



power is produced in the detector by mixing the blackbody radiation with the laser radiation. The blackbody radiation is chopped with a room temperature chopper and the IF signal is spectrally decomposed with a tunable bandpass amplifier (IF system) the output of which is detected with a lockin amplifier. By tuning the center frequency of the IF system and monitoring the system response the detector frequency response is measured.

III. Review of Experimental Results

During the last year we have seen progress in our work on Ga:Ge photoconductors This progress has been in three areas:

1. Increased detector bandwidth,
2. Increased detector responsivity,
3. Reduced system temperature.

Table 1 displays the results of our measurements of detector bandwidth.

TABLE 1

Crystal	Detector Number	Acceptor [1/cm ³]	Donor [1/cm ³]	Thickness [mm]	Bandwidth [MHz]	Bias [mVolts]
108-17.7	006	2×10^{14}	1.0×10^{12}	1.0	2.5	350
	007	1.1×10^{14}	1.5×10^{13}	0.5	9.0	200
S17-16.7 (9.5)	008	2×10^{14}	1×10^{14}	0.5	20.0	280
"	"	"	"	"	10.0	380

The detector bandwidth increase results from changing detector doping levels. We now know how to modify the doping levels in such a way that the detectors can be made faster. This, however, leads to a decrease in the detector responsivity because as the carrier lifetime (T_c) decrease the photoconductive gain is reduced since the photoconductive gain is proportional to

the ratio of the carrier lifetime (T_c) to the transit time (T_t) between the electrodes

$$g = \frac{T_c}{T_t} .$$

This decrease in the detector responsivity is counteracted by slicing the detectors thinner and thus reducing the transit time. Increasing the detector responsivity by a factor of two results in a four fold increase in signal to noise. More importantly, the increase in bandwidth was achieved while we also achieved a substantial decrease in the system temperature.

The system temperature has been decreased from 200,000 K to 56,000 K. Figure 2 shows a typical data set for detector #7. This data corresponds to a system temperature of 56,000° K and a bandwidth of 9 MHz. However, this system temperature represents only that obtained in the present test system. It could be reduced by a factor of 10 in a practical system by reducing the optical losses in the system to the currently available state of the art.

Table 1 also shows the first heterodyne measurements of a Ga:Ge detector's bandwidth changing with bias voltage. This result is constant with the Hall effect measurements that have been made by Haller.

HgCdTe detectors, constructed at Essex University, had been tested in Bonn, Germany with some indication of a large bandwidth and sensitivity. However, tests on the same units here, brought over by a member of the Essex University team, showed rather poor responsivity. We conclude that Ga:Ge is the best FIR heterodyne material presently known. However there may be Germanium systems with other dopants which are also good.

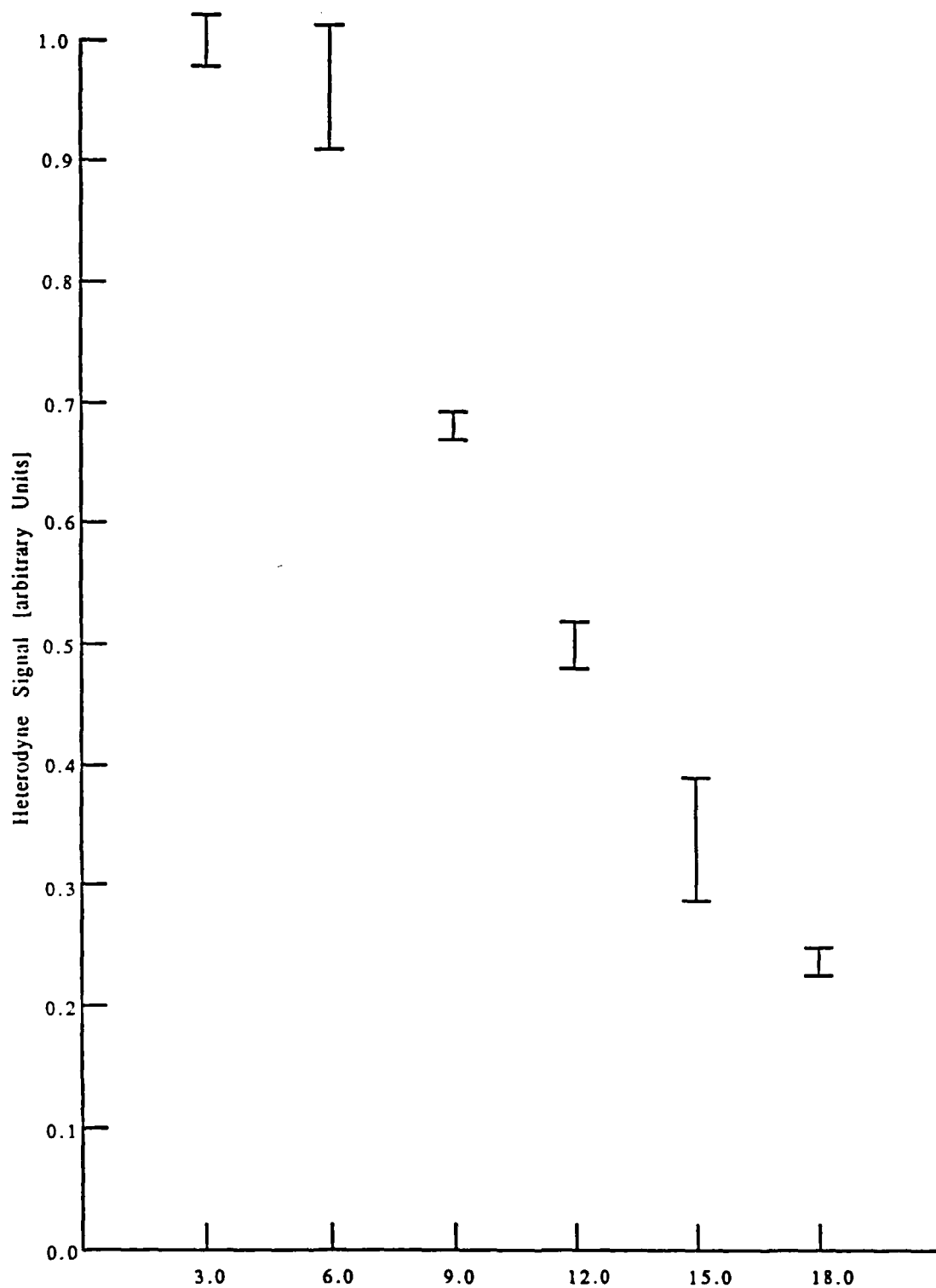
IV. Conclusion

We have more detector material being processed and are having this material characterized (donor and acceptor concentrations measured) before we begin

Figure 2

Heterodyne signal from Ga:Ge Detector #7 as a function of
Local oscillator - signal frequency separation

R=21,500 t=12.5 sec Vbias=250 mv VLO=13.6 v VBB=-13mv B=3 Mhz



Signal - Local Oscillator Frequency Difference [MHz]

detector fabrication and a new round of measurements, which we hope to carry out even though our contract for such work is completed. The detector responsivity will decrease as we increase the bandwidth further and so a device is currently under construction to put stress on the detector and thus shift the band edge to longer wavelengths. Because the local oscillator is at a frequency very close to the band edge where the quantum efficiency is not high, a modest stressing of the detector should result in a shift sufficient to increase the detector responsivity by an order of magnitude.

Considerable progress has been made on characterizing heterodyne detector response, increasing detector responsivity, increasing detector bandwidth and decreasing system temperature. We intend to continue making measurements as new detectors become available.

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